A7.10 STRUCTURE OF ELECTRON BUBBLES IN LIQUID HELIUM FROM PHOTO-EJECTION UNDER PRESSURE. C. Zipfel and T. M. Sanders, Jr. H. M. Randall Laboratory, University of Michigan, Ann Arbor, Michigan 48104, U.S.A.

Experimental study of electron ejection from bubble states in liquid helium by electromagnetic radiation has been extended to high pressure. Previous work[1] at the vapor pressure established the existence of the effect, but left several ambiguities in interpretation. These ambiguities are removed and a unique determination of the bubble parameters and their pressure dependence is possible if, in the present experiment, we assume that the electron makes a simple transition from the 1s state in the bubble to the continuum.

The experimental technique is that of ref. 1, except that the cell is sealed and connected to a room temperature gas-handling system by capillary tubing. Quartz optical windows are sealed with indium wire gaskets and are tight to HeII under pressure. The detection scheme consists of a Cunsolo[2] mobility apparatus operated slightly beyond cut off, so that current appears when unusually fast carriers, such as ejected electrons, are produced by the incident light. This current, which is synchronous with the chopped light, is lock-in detected. As the data are being taken the ratio of this signal to a voltage proportional to the light power is plotted against the wavelength of the incident radiation.

Photo-ejection spectra taken at two different pressures are shown in Fig. 1. Note that as increased pressure is applied the maxima shift toward higher photon energies, as would be expected if the bubble radius shrinks under pressure. The higher energy peak is the one identified as the principal maximum in ref. 1. Under pressure, it will be observed, a very much stronger peak appears at lower energies. In the range of energy available to us (0.5 to 3 eV) we have not detected a low energy peak at pressures below 10 psi. It is the appearance of this new maximum which permits a unique determination of the bubble parameters.

We have performed theoretical calculations of the cross section for the ejection of an electron from a square well potential for a range of values of the well depth, V, and the well radius, R[3]. We have adjusted R and V to fit the positions and the relative heights of the two peaks. We show in Fig. 1 theoretical cross sections calculated for the fitted values of the well parameters. We have not attempted to measure absolute cross sections, and have normalized the curves. We consider the correspondence between theory and experiment to be good enough so that the well parameters can be determined unambiguously at each pressure.

Figures 2 and 3 show derived values of bubble radius and well depth plotted against pressure. The radius values can be compared with those derived from

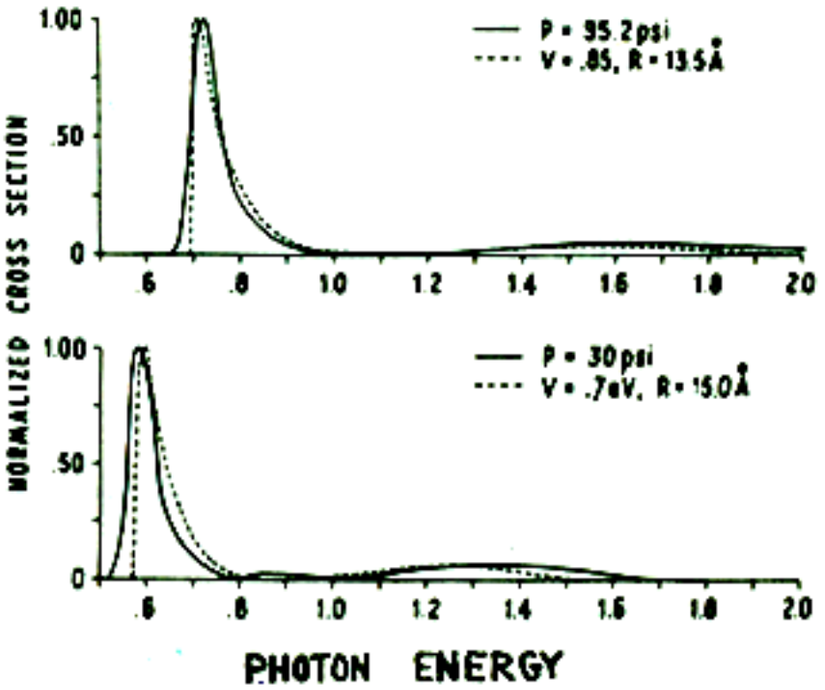


Fig. 1. A comparison of experimental and theoretical cross sections at different pressures. The solid lines are the experimental curves; the dashed lines are the theoretical curves calculated for the indicated well parameters.

analysis of the lifetimes of electrons trapped on vortex lines in rotating liquid helium[4]. As this method depends on classical analysis of superfluid flow outside the bubble it yields an external, hydrodynamic radius. The value derived from the present experiment involves electron wave functions and energy levels inside the bubble and might be called an internal, quantum mechanical radius. In this light the agreement is remarkably good.

The pressure (or density) dependence of the well depth has not been measured previously, although there are published results for the value at the vapor pressure[5]. Our well depth is significantly smaller than the previous experimental values. It is also well below the theoretical value calculated by the ansatz of replacing the liquid by a crystalline

solid[6]. In fact, the value at the vapor pressure is much closer to one derived optically for a random array of helium atoms[7]. Under pressure the values become closer to those calculated for a crystalline helium. It would be interesting to extend the optical method to include effects due to two-particle correlations.

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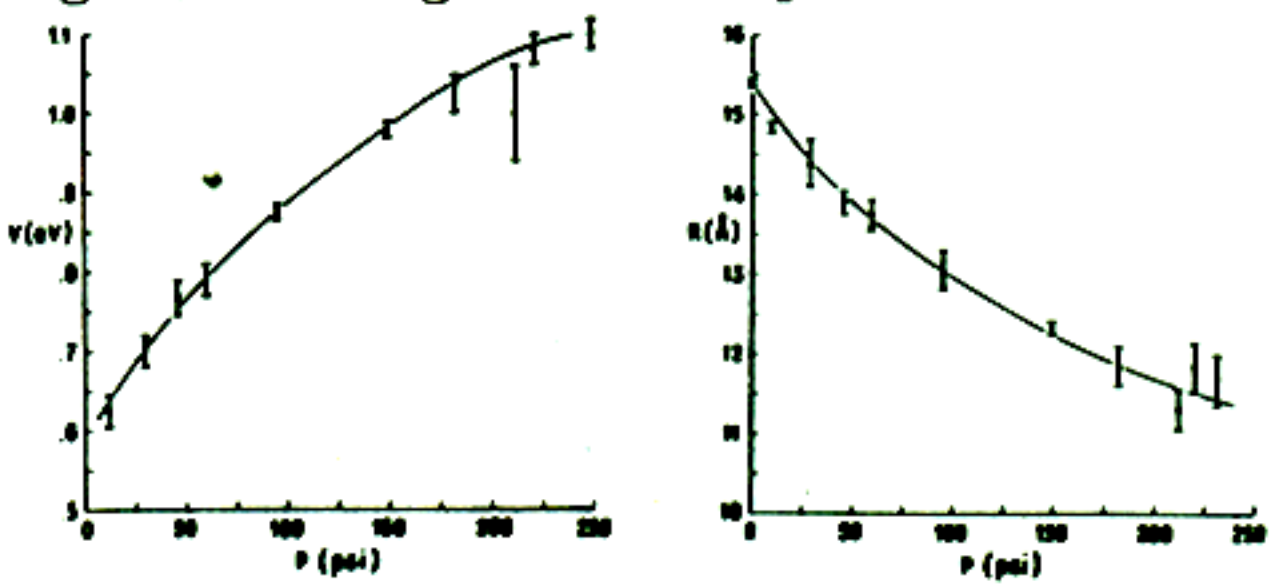


Figures 2 and 3. Well depth and radius vs. pressure.

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(A7.11) Stability of Charged Vortex Rings. L. Bruschi, P. Mazzoldi and M. Santini. Istituto di Fisica, Universita di Padova, Padova - Italy.

Discussion A7

A7.2 (G. Gamota and T. M. Sanders, Jr.)

Q. G. W. Rayfield (Oregon) Did you just use the free ion mobility for the frictional force on the ion bound to the vortex ring?

A. Yes. In this experiment the ion is not moving relative to the core, but with the vortex ring through the fluid so we assumed the free ion mobility.

A7.3 (S. Cunsolo, B. Maraviglia)

Comment C. M. Surko (Berkeley) Reif and myself have carried out similar experiments with strikingly different results: in particular we find that electrons, arriving at the liquid surface trapped in vortex rings, emerge from the liquid surface with energies less than 0.3 eV irrespective of the energy of the vortex rings ranging from 5 to 50 eV. Positive charge carriers arriving at the liquid surface trapped in vortex rings were not observed to be extracted from the liquid surface even in the presence of electric field across the surface as large as 100 volts/cm.

A. Indeed, as it came out from our previous discussion, we use similar experimental arrangements. In my opinion the spreading of the ejected charges causes a reduction of the collected current; and having in your experiment only a current due to vortices, that is 50% of the whole (for us it is 90%), you hardly can determine the energy spectrum. The fact that you do not see positive current supports this hypothesis. Actually we find a reduction from liquid current to interface positive current of about twenty times. This causes the disappearing of the current in your experiment because it is buried in the neutral current.

Q. C. S. M. Doake (St. Andrews) Did you notice any hysteresis effects when applying a reverse voltage to cutoff the positive current present in zero field?

A. Actually we did not notice any effect of this kind, as you see in St. Andrews.

Q. G. Gamota (Bell Labs) Why was the data not extended to higher voltages?

A. Because in liquid it becomes inaccurate to make measurements above such voltages. Actually the current-voltage characteristic at higher voltages has a negative slope, that might

depend on ionic beam spreading. Obviously the determination of the energy of ejected charges is at least as inaccurate as the determination in liquid.

A7.4 (D. A. Neeper, L. Meyer)

Q. G. W. Rayfield (Oregon) Recently Rayfield has reported work done in $He^3$-$He^4$ mixtures which indicates the structure of the negative ion is altered by the presence of $He^3$ impurities. The results observed by Neeper and Meyer could be accounted for by the presence of very small quantities of $He^3$ dissolved in the $He^4$ used for the experiment. Was special care taken to purify the $He^4$ used in the present experiments?

A. No.

A7.5 (S. Cunsolo, B. Maraviglia)

Comment L. Meyer (Chicago) K. Schwarz and R. W. Stark measured the drift velocity of negative ions as a function of field at 0.5°K. The velocity is proportional to the field within 1% up to 16 m/sec.

A. This is just the result we obtain for bare ions, so there is perfect agreement.

Q. A. Gamota (Bell Labs) Is the data similar for positive ions?

A. Yes, as far as threshold fields are concerned. Measurements are in progress for the bare ion critical velocities.

Q. A. L. Fetter (Stanford) Do you interpret your experiment as providing evidence for the Huang-Olinto theory? Which part of the theory do you support?

A. The threshold field $E_{c1}$ in the temperature range $0.5°K < T < 0.8°K$ is in agreement with the stability condition fixed by the H-O theory. Nothing can be said as far as the creation threshold is concerned.

Q. J. Lekner (Cambridge) I think the temperature dependence of your critical field, which goes as $T^3$, can be interpreted as a $T^{-3}$ dependence of the mobility of the ions. Do you agree?

A. Yes.

A7.6 (M. Cerdonio)

Q. G. W. Rayfield (Oregon) Is it possible the jumps in mobility observed earlier by Careri might be due to changes in the flow patterns of the quasi particles about the ions? This would be similar to turbulence in normal fluid at higher temperatures.

A. Actually our experiment rules out any process based on a single interaction which should take an appreciable fraction of the time of flight. So, a process such as you describe

is compatible with our results.

Comment P. W. F. Gribbon (St. Andrews) Cope has also investigated the dependence of step size on the length of ion flight path and finds no variation of step size. This is another confirmation of the disagreement of Huang-Olinto theory with experiment.

Comment J. Cope (East Anglia) The Huang-Olinto theory in the low field region also predicts that successive discontinuities increase in magnitude for higher orders whereas our experimental evidence is that the first three discontinuities are of equal size.

Comment C. di Castro (Rome) The measured ion velocity does not depend on the length of the cell if one allows for multiple creation of vortices by each single ion as in the model proposed by myself (Nuovo Cim. 42, 251, 1966) which is not in contradiction with the present experiment.

A. I agree.

A7.7 (C. E. Chase, F. Dupré, M. V. Ricci)

Q. T. M. Sanders (Michigan) I wonder if there should be a difference between Hall mobility and drift mobility for a heavy ion drifting with only slight random motion? The situation is very different for an electron in a solid, where you have a random walk with a slight drift superimposed.

A. I am not sufficiently familiar with the details of the theory, which was developed by Dr. Dupré, to answer this question. However, even if the large positive ion mass reduces or eliminates the difference in mobilities, it might still be present for negative ions. We are examining both species.

Q. P. W. F. Gribbon (St. Andrews) You showed a second step for positive ions at $T \sim 0.7^{\circ}K$. Cunsolo found a velocity corresponding to the second negative step at lower temperatures. Does the first step disappear at $T < 0.9^{\circ}K$ in your work?

A. No, the first step as well as the second is still present for positive ions, but we have not delineated it yet in much detail.

Q. C. S. M. Doake (St. Andrews) From your results is it possible to say the discontinuity in the mobility of ions is due to roton interactions, and not phonons?

A. No.

A7.9 (B. E. Springett)

Q. L. O. Roellig (Wayne) Were all the experimental points taken at the same temperature?

A. No - mobility data at 283°K, trapping from 1.7°K to 1.1°K. One would not expect the bubble radius to be much affected by temperature, except in the region where the surface tension is varying strongly, and then only the value near P = 0.

A7.10 (C. Zipfel, T. M. Sanders)

Q. W. Triftshäuser (N. Carolina) Did you perform any measurements at different temperatures and did you find any change of the well depth as a function of temperature?

A. We have made measurements only at 1.3K.

Q. W. Zimmermann (Minnesota) Have you looked for changes in mobility at wavelengths corresponding to transitions to excited bound states?

A. No, but our present apparatus uses glass windows, and we cannot use much longer wavelengths.

Q. B. L. Springett (Michigan) How did you scale the surface tension in your theoretical fit?

A. We used the macroscopic surface tension at the vapour pressure and scaled in proportion to the density. This may not be the best choice.

Q. D. G. Onn (N. Carolina) Do you have any idea how long the free electrons remain free before being re-trapped in the bubble state?

A. Not from our experiment. The singlet positronium experiment of Stewart and Triftshäuser seems to indicate a bubble formation time less than or of the order of $10^{-10}$ sec.